World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

Check for updates

Social-economic factors influencing the adoption of improved energy technologies in Makueni and Machakos counties, Kenya

Samson M. Muloo [1,*], Jacinta M. Kimiti [1], Muusya Mwinzi [1] and George M. Muthike [2]

[1] *Department of Environmental Science and Land Resources Management, School of Agriculture, Environment, Water and Natural Resources, South Eastern Kenya University, Kenya.*

[2] *Forest Products Development; Kenya Forest Research Institute (KEFRI), Kenya.*

World Journal of Advanced Research and Reviews, 2023, 18(01), 269–288

Publication history: Received on 25 February 2023; revised on 04 April 2023; accepted on 07 April 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.18.1.0586

Abstract

Many peri-urban and rural households use traditional stoves which have low energy use efficiency leading to wasteful use of woodfuel, increase in indoor air pollution and putting more pressure on biomass sources. Energy saving devices have been introduced which are environmentally friendly and economical. The main objective of this study was to establish social-economic factors influencing the adoption of improved energy Multistage sampling technique was used whereby; locations and sub-locations were selected purposefully. Households from four sub-locations were chosen using simple random sampling. A total of 232 households in the four selected study areas were interviewed. The study used questionnaires and interview schedules for data collection. The collected data was coded and entered into the computer for analysis using the Statistical Package for Social Sciences (SPSS) and statistics and data software (STATA) presented using tables. Data forecasting analysis was done using the Time series Autoregressive Integrated Moving Average (ARIMA) time series model for the period 1991 to 2052. Family size had a significant effect on use of LPG (χ^2 = 22.010, P = 0.001) and electric energy technology (χ^2 = 20.482, p = 0.002). The result of this research further showed that for the respondent to get kerosene lamps, in Unoa, Kilili and Mung'ala, they travelled more than 1 km whereas in Kilili, they mainly (18.6%) travelled 101 – 600m for the energy device. This showed a significant different in the distance travelled in the four areas (χ^2 = 86.194, P = 0.0001). The outcome of the research is useful to many stakeholders including the government, Ministries of Agriculture and Energy, Environmentalists, Market Suppliers of improved energy devices and Researchers.

Keywords: Adoption; Improved energy; Social-economic Factors; Kenya

1. Introduction

Globally around 3 billion persons count on conventional fuels for cooking as well as heating (EIA, 2017). Forest cover 31percent of earth's land surface however, the area is diminishing, with 420 million hectare of forest lost through deforestation for woodfuel between 1990 and 2020 (Food and Agriculture Organization (FAO), 2022). Demand for energy and related services is rising globally in order to satisfy social and economic development goals as well as enhance welfare plus health of people. This is affected by the climatic change which has led to the diminishing of energy resources day after day (Panepinto, 2021). The amount of wood charcoal produced worldwide tripled from 17.3 to 53.1 million tonnes between 1964 and 2014. Currently, 61% of the world's production is made in Africa, mostly to meet the needs of urban and peri-urban households for cooking fuel. (Doggart & Meshack, 2017).

* Corresponding author: Samson M. Muloo

It is easiest to understand the energy sector of Africa as three separate regions. South Africa relies on coal, North Africa is mostly dependent on oil and gas, and the remainder of Sub-Saharan Africa is largely dependent on biomass. (Sawin, 2017). Many times, biomass energy is used in its conventional and unprocessed form, which includes a variety of natural organic fuels like wood, charcoal, agricultural byproducts, and animal waste. Even oil-rich Sub-Saharan African nations still count on biomass energy to supply the majority of their domestic energy needs: In Ghana, for example, about 40 % of total primary energy come from biomass mainly woodfuels (Energy Commission (2016). There are significant environmental limitations to using traditional biomass energy. In highland regions of Sub-Saharan Africa, indoor air pollution from unvented bio-fuel cooking stoves is a significant cause of respiratory ailments. Land degradation is encouraged by a reliance on biomass. The need for charcoal appears to be a factor in some places, such as the areas surrounding important towns like Lusaka, Dar es Salaam, and Nairobi. (Kiruki, *et al.*, 2017). Africa's Sub-Saharan region is the least electrified, consequently, the area is viewed as the perfect location for the deployment of cutting-edge electrification technologies that will be both environmentally friendly and economical. Renewable energy technologies are often recommended as the most appropriate energy technologies of choice for rural Africa. According to Nahar, (2016), majority of home cooking is done by women, who are exposed to twice as much particle pollution and are typically twice as likely to develop respiratory infections as males.

Fossil fuels power give around 80% of Kenya's industrial sector, accounting for 28.57% of the country's energy consumption, posing a risk to the country's economic stability (IEA, 2015). Therefore, increasing the number of households using better biomass stoves is a crucial sustainability approach that should be implemented in Kenya (IEA, 2017). According to Machakos Integrated County Development Plan (MICDP, 2018), Most of the Machakos County residents use firewood and charcoal as source of fuel for cooking. This has resulted in deforestation in most areas leading to rampant and expansive soil erosion. On the contrary, by the year 2022, Makueni County proposes to promote the installation of biogas systems and small scale solar lighting facilities at the household level. This will ensure that at least 30% of households use solar energy for lighting and cooking. By the end of the period, the initiative targets to connect 15,000 households with solar energy ensuring the exploitation of improved energy generation from wind, solar and biogas. Through partnerships with the private sector, the Makueni County targets to generate 20 Mw of power from solar through installing solar plants and 5 Mw from wind sources through installing wind plants in the plan period this will promote improved energy technology utilization at a greater percentage (Makueni integrated County Development Plan (MICDP, 2018).

1.1. Importance of Energy to the Economy

In the world today, about 100 million people face fuel shortages as wood fuel supplies diminish (FAO, 2017). Statistics by FAO, (2018), state that wood fuel provides more than 70 percent of energy in 34 developing countries and more than 90 percent in 13 countries (including 11 in Africa). In Kenya, more than 85% of people still use traditional fuels such wood, charcoal, as well as agricultural waste for cooking and heating. (Pilishvili, *et al.,* 2016). However, for most economies, especially the developing economies, only the conventional types of energy (petroleum, electricity) are considered while computing Gross National Product (GNP). Energy is now widely acknowledged to be a necessary but insufficient condition for economic progress (Federal Emergency Management Agency (FEMA), 2007). Most if not all the developing countries rely on biomass energy as opposed to other forms of energy like electricity and petroleum. At the individual level energy fulfils basic human demands for cooking, lighting as well as heating, while it plays a decisive role in employment and income creation at the national and local levels (Mills, 2016).

Households, enterprise sectors (including industry, large, small, and medium enterprises), building and construction, *jua kali*: transport, agriculture, service sectors (Information and Communication Technology, financial and banking, and tourism), basic services - health, education, water, electricity generation, and government - civil and military - are just a few of the various economic sectors that depend on energy (Tun, 2019). According to UNEP, (2017), wood fuel consumers include rural households, peri-urban and also urban households, industries and institutions. However, studies generally categorize consumers of energy in Kenya into five sectors: household, commercial, manufacturing, transport and agricultural (IEA, 2015). The same broad categories are supported by Bhagavan, (1996) who states that the Kenyan economy relies on six different types of energy: wood fuel, petroleum fuels, electricity, ethanol, wind and solar, with the last two sources of energy being limited in use.

1.2. Global Environmental Challenges and Energy Needs

Global emissions of greenhouse gases into the atmosphere have been abruptly exaggerated especially in the last ten years **(**IRENA**,** 2018). Without enough time for the capital basis of natural resources to regenerate, this has led to extensive environmental damage (Bergmann, 2019). According to Doggart & Meshack, (2017), worlds emissions and cumulative emissions are estimated to be 6.7 billion tons of carbon by 2050.The overexploitation, depletion, and degradation of natural capital, including ecosystem products and services and natural resources, have been caused by this economic expansion, often known as the "brown economy. Sub-Saharan Africa has also the lowest electricity rate worldwide. In 2008, it was 28.5% which means that as many as 587 million people were without access to electricity (World Bank, 2017). United Nations' Food and Agriculture Organization (FAO) has estimated that in the coming decades the total fuel wood consumption will continue to grow. This is promoted also by the population growth and the rising fuel prices (FAO, 2019). The likelihood of land degradation will rise when food and energy production take place in the same region. While many individuals are need to expend a great deal of time and effort to meet their daily energy needs, East Africa might be said to be experiencing chronic power poverty (FAO, 2019). In Kenya, wood fuel meets the energy demands of the traditional sector, which includes rural communities and the urban poor. Petroleum and electricity are the main drivers of the modern sector of the economy (UNEP, 2017).

1.3. Global Wood fuel situation

In 2000, there were over 3.9 billion cubic meters of wood produced, of which 2.3 billion cubic meters were utilized for wood fuel. This means that almost 60% of all wood harvested from forests and non-forest areas around the world is used for energy purposes (FAO, 2018). Thus efforts need to be made to reduce the demand for wood biomass and thus conserve the forests and the environment. Asia and Africa produce over 75% of the woodfuel (African Development Bank (AfDB), 2017). The projections of global woodfuel consumption by 2010 ranged from 1.5 billion m^3 to 4.25 billion m^3 (FAO, 2018).

1.4. Wood fuel situation in Africa

Over 90% of the wood harvested from forests in Africa is used as fuel. The bulk is used as wood fuel directly, while a variable but significant amount is converted into charcoal. Charcoal is the most significant source of domestic energy in many African cities, with more than 80% of it being utilized in urban areas (FAO, 2018). The most significant biomass is wood, but the reliance on it varies across many different countries. Some nations, like Nepal in Asia, Kenya, Uganda, Rwanda, and Tanzania in Sub-Saharan Africa, rely at least 80% of their entire energy needs on wood fuels. Table 2.1 shows that there will be greater demand for wood fuel by the year 2030 in Africa and yet there is a scarcity in its supply currently. Therefore, it is necessary to introduce technologies that reduce the use of woodfuel in order to make its use sustainable and to promote afforestation and re-afforestation.

Table 1 FAO projections of woodfuel consumption in Africa from 1970 to 2030

YEAR	1970	1980	1990	2000	2010	2020	2030
Fuel-wood (million m3) Africa	261.1	305.1	364.6	440.0	485.7	526.0	544.8
Charcoal (million tons) Africa	8.1	11.0	16.1	23.0	30.2	38.4	46.1

According to Tun (2019), statistics provided by Camco Global show that woodfuel is one of the major causes of environmental degradation and accounts for about 18% of the world's GHG (greenhouse gases). Most households in developing countries use traditional stoves, for example the three stone and the metallic charcoal stoves which are less efficient in energy saving. The issue of over-exploitation of forested lands is one that many Sub-Saharan African nations face. In terms of biomass yield, large areas that were formerly very productive have been utterly exhausted. Estimates show that excessive clearing and poor management result in the annual loss of about 11 million hectares of tropical forests (FAO, 2018). This removes the ground cover, rendering the land susceptible to soil erosion and hastening land deterioration. It also reduces one of the main sources of wood fuel, leading to a fuel shortage

1.5. Wood fuel situation in Kenya

An estimated 40.5 million tonnes of biomass are needed in Kenya today, but only 16 million tonnes are available sustainably (UNEP, 2017). Biomass energy (mainly firewood and charcoal) constitutes 70 per cent of the national energy supply, 90 per cent of which is consumed by households (Lambe, 2015). The most important energy sources in Kenya still are, and will continue to be, firewood and charcoal. Over 90% of people use firewood for cooking and warmth, making it mostly a rural fuel. With 82% of the population living in cities using charcoal, cities are where it is most commonly used. Because there is less wood available, certain regions of the country use agricultural waste and animal dung as a source of cooking energy (Sikei, *et al.,* 2009). Since cooking is one of the most energy-efficient end uses, woodfuel must be improved because it is a major source of energy in rural areas of many developing nations. One way to achieve this is by substituting the upgraded stove for the conventional "three stones" method (World Bank, 2019). In Makueni, 77.9% of total residents use firewood while 10.6% use charcoal (MCSP, 2019). More research is needed to determine how this valuable resource may be used responsibly because it plays such a significant part in the majority of Kenyans' daily lives. According to Oduor & Githiomi, (2012), the conservation of wood energy should be given a priority through the promotion of improved stoves with higher efficiency.

1.6. Adoption of Renewable Energy Technologies in Kenya

According to International Energy Agency (IEA, 2017), the energy obtained from unlimited sources, rapidly replenished or naturally renewable are termed alternative sources of energy. The Kenya Vision 2030 indicates that energy transition is primal to the realization of the socioeconomic pillars within the development framework of the vision. It stipulates that the government is committed to continuing institutional reforms in the energy sector and that new sources of energy will be found through the exploitation of renewable energy (Pilishvili, *et al.,* 2016). The vision acknowledges that energy connects the overall development of all the remaining pillars. Accordingly, the ministry of energy is making efforts to include the usage of renewable energy sources in the energy mix. The Scaling-Up Renewable Energy Program in Low-Income Countries (SREP), from which Kenya is one of the six pilot countries to benefit, is one of these obvious measures (Pilishvili, *et al.,* 2016). Most rural catchments count on paraffin and wood fuels to match their daily energy demands.

1.7. Worlds view on biomass energy saving stoves

In the late 1990s and early 2000s, there emerged the second generation of cooking stoves, which, while more expensive, were constructed of more durable materials. Examples can be found in both Latin America and China. In Latin America, the Plancha so-named because of its prominent metal griddle (*plancha*) was disseminated under Guatemala's social fund program. A more expensive, durable stove lasting a decade or more, the Plancha has a metal top used for roasting corn and preparing tortillas and other staple foods, a shelf for feeding wood, space on top for placing cooking utensils and equipment, and a chimney for venting smoke. Having a durable stove with many convenient features, combined with the freedom to select options it led to a high degree of continued stove use (Johnson and Chiang, 2015). China's experience provides ample evidence that the development of a program for better cooking stoves can succeed, given that more than 100 million improved cooking stoves are still in use. China has achieved the largest improvement in energy efficiency as a result of its programs in the 1980s and 1990s (Yang, *et al.,* 2014). According to Papada & Kaliampakos, (2020) the failure to adopt better charcoal stoves in urban Zanzibar was mostly attributed to poor quality of the improved stoves, pricing, information, and education on the stoves.

People base their purchases of devices on actual prices, according to Elvira (2008), and are generally unaware of the operational costs. According to IRENA (2018), technology diffusion is limited by the unavailability of information and proposes that the best sources of information are the people who have already adopted the technology. One nation with a successful improved stove program is China, which by the early 1990s had distributed 120 million upgraded stoves to rural areas (Johnson & Chiang, 2015).

1.8. Energy saving stoves *(jikos)* in Kenya

According to Njenga, *et al.,* (2017), in Kenya there are modern woodfuel saving stoves which include; ***Kenya Ceramic Stoves-*** the Kenyan Ceramic Stoves (KCJ) is a light, portable charcoal burning stove consisting of two distinct units- a metal cladding and a ceramic liner. ***Kuni Mbili Stove*** is a cook stove that is designed to take two pieces of firewood at a time (Wafula, *et al*., 2000). ***Maendeleo Stove-*** a device developed to replace the three stones with an inbuilt ceramic liner that is inverted, bell-bottom shaped with an opening for feeding woodfuel, and V-shaped pot rest ***Woodfuel energy-*** Energy or heat obtained from the burning of woody biomass (either firewood or Charcoal) Muchiri, (2008). ***Stoves Star***-According to Muchiri, (2008) and Wafula, *et al*., (2000), a Stove Star is easy to light, saves on Charcoal consumption, is safe, easy to use and maintain, efficient, long-lasting and portable. ***Kunimbili* Stove-**This is a highly efficient wood stove which can also use charcoal. It's especially designed to reduce charcoal consumption, and carbon monoxide emission and last longer. *Kunimbili* stove is easy to light, saves on woodfuel consumption, is safe, easy to use and maintain, efficient, long-lasting, portable and comes with a 6 months' warranty (Majid, 2006). According to Githiomi, *et al.,* (2011), by assuming that households that were using three-stone fires with an efficiency of 10% will gradually switch to more efficient technologies like upgraded firewood and charcoal stoves, the adoption of efficient technological devices will help to reduce the deficiencies in woodfuel. This suggests that a sizable amount of wood fuel will be conserved, lowering consumption.

Scode gasifier stove -According to (Lotter, *et al.,* 2015), this is a single pot forced draft front loading concrete highly efficient cooking stove that has a fan that is powered by either solar or battery or electricity. The fan provides air for the complete burning of wood fuel hence reducing smoke emissions (Njenga, *et al.,* 2017). It has a capacity of sixty (60) litres and can cook for up to 150 persons. Scode gasifier stove uses multiple fuels e.g. firewood, pellets, charcoal, dry maize cobs etc., is fitted with a solar or electrically powered (low consuming) fan, saves up to 50% of the wood fuel, reduces smoke emissions by 60%, cooks faster than a normal stove and is long-lasting (Jeffery, *et al.,* 2015). ***Kisasa stove*** -According to (Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), 2016), *kisasa* stove a portable pottery cylinder (ceramic liner) that is installed by building mud or concrete surrounding the kitchen. It is suitable for use in households and institutions with a permanent fireplace. *Kisasa* stove is easy to install and maintain, is easy to light, saves on woodfuel consumption, produces less smoke and more efficient than the traditional 3 stone fire.

Rocket stove -A Rocket stove is a firewood burning stove. There are three types: Mud, mud-brick and cement brick rockets. It cooks faster, is fairly affordable and reduced emission to the environment. The sizes vary with each household and/or institution. It saves on woodfuel consumption, are easy to use and maintain, produce less smoke, is easy to light, cook faster, safe to use, long lasting and 6 months' warranty (Karekezi & Kithyoma, 2002). ***Institutional stoves*** are highly efficient, large heavy-duty cooking stoves that use firewood. They save on fuel costs, time and energy Muchiri, (2008). ***Fireless cooker (food warmer).*** This is an insulated basket, container or box that is especially designed to complete the cooking that has been done partially on conventional cooking technologies. It is also a food warmer for it keeps food hot for up to eight (8) hours after cooking (Mugo & Gathui, 2010). This cooker reduces the consumption of wood fuel by about 40%.

1.9. Solar energy base in Kenya

Kenya is located along the equator where there is adequate radiant energy from the sun which is the most important parameter when exploiting solar resources (Broesamle, *et al.,* 2001). Kenya has year-round Direct Normal Irradiance (DNI) of 6 kWh per m2, which is suitable for solar thermal uses and energy generation. Communities should aim to employ solar energy technologies since they are the most practical low-carbon options for supplying their lighting and cooking needs, as well as a variety of other energy needs at the domestic and industrial levels. (Ministry of Energy, 2004). According to Duffie & Beckman*,* (2013) the main solar appliances which are either powered by sunlight, either directly or through electricity generated by solar panels include; solar panels, solar lamps, solar torches, solar chargers, solar batteries, solar air conditioning, solar balloon, solar charger, solar backpack, solar cell phone charger, strawberry tree, solar chimney, solar calculator, solar-powered waste compacting bin, solar cooker, solar dryer, solar-powered fan, solar furnace, solar inverter, solar keyboard and solar lamp (Foster, *et al.,*2009). Solar pond, solar road stud, solar street light, solar traffic light, solar *tuki*, solar-powered flashlight, solar notebook, solar-powered calculator, solar-powered desalination unit, solar-powered pump, solar-powered fountain, solar-powered radio, solar-powered refrigerator, solar-powered stirling engine, solar-powered watch, solar-pumped laser, solar roadway, solar Spark lighter, solar still, solar tree, solar vehicle, solar boat, tûranor planet solar solar bus, solar car, solar golf cart, solar panels on spacecraft, solar sail, solar thermal rocket, solar operated automatic milk Collection unit, tracker, windmill, fan, computer, solar water heater and solar holiday lights (Smith, 2011).

2. Material and methods

2.1. Study area

The study area fell within Makueni and Machakos County each having two study sites which were rural and peri-urban. The rural study sites included Kilili sub-location in Makueni County and Kinoi Sub-location in Machakos County while the peri-urban sites included Unoa sub-location in Makueni County and Mung'ala sub-location in Machakos County.

2.2. Makueni County Study Sites

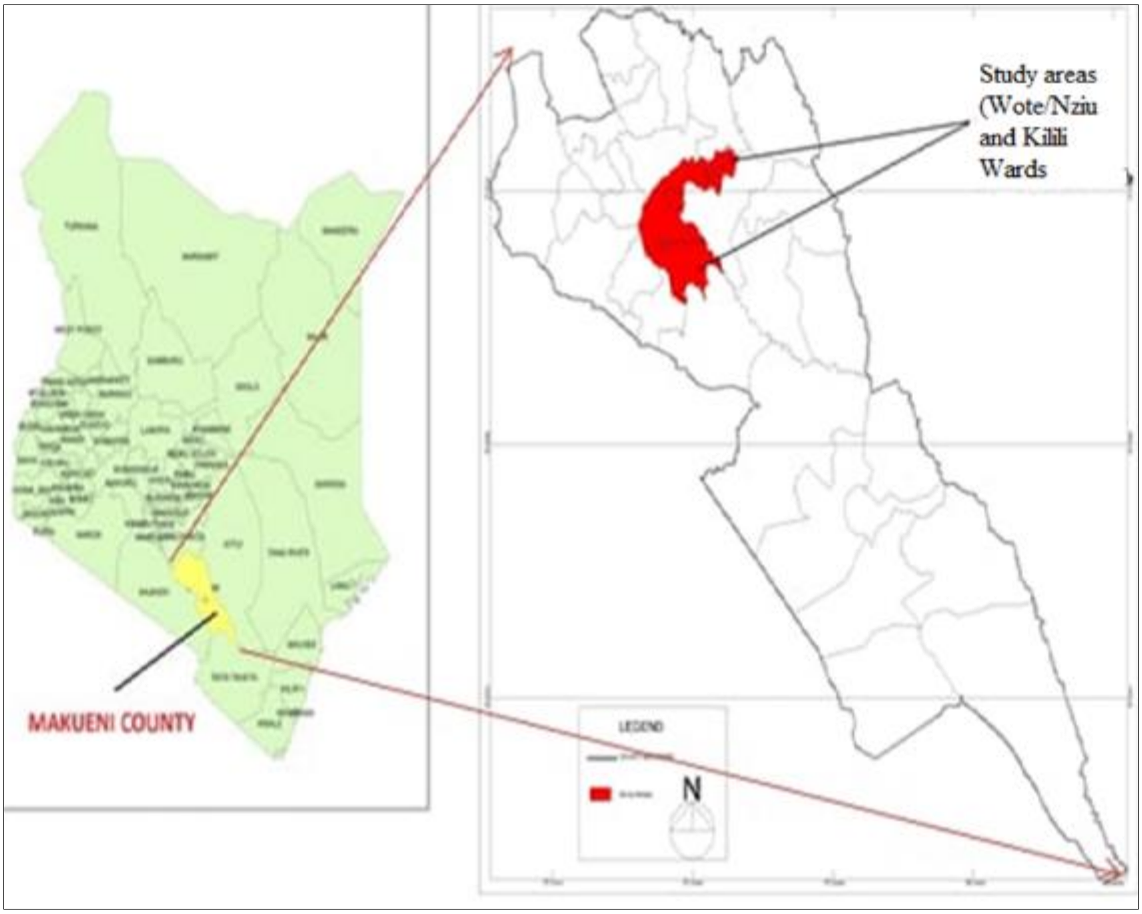
The choice of the study sites was informed by their accessibility. Unoa Sub-location in Wote Sub-County, Makueni County, was one of the study sites in Makueni County. This site has in the recent past witnessed increased demand for both charcoal and firewood as the most common source of fuel by the surrounding urban dwellers. The area is also characterized by the clearance of indigenous trees and shrubs to create room for horticulture farming which has a ready market at Wote town owing to its proximity (Kieti, *et al.*, 2016). This in turn has led to a scarcity of fuel wood due to the clearance of trees. The overspill of both commercial and residential developments into the agricultural fields in the area has also led to an acute shortage of vegetation (Bhatta, 2010). Wote Sub-County, has five locations which include Kako, Kikumini, Muvau, Nziu and Wote. Wote location has two sub-locations, Kamunyolo and Unoa where the study was conducted. The population of the Unoa sub-location is 4,212 with 218 households covering an area of 54.57 Km2 and a density of 193.17 (Table 2).

The second study site was Kilili Sub-location in the Nzaui/Kilili/Kalamba ward in Makueni County. The information on the improved economy most likely may not have reached this area hence using the only available government forest (Nzaui forest) and available trees in their home gardens as a source of wood fuel. The Nzaui forest is already invaded by the residents for charcoal and firewood leading to deforestation (MICDP, 2018). Population, Area in Sq. Km and Density by Administrative Units of Kilili Sub-location (Appendix 2).

Table 2 Population, households, area in square Km and density by administrative units of Unoa Sub-location

Division	Number of locations	Number of sub-locations	Population	Households	Area (km^2)	Density
Kaiti	4	10	45,106	9136	230	218.96
Kee	2	6	14,409	3293	46.84	320
Wote	Kako	1	6792	1410	54.52	124.59
	Kikumini	2	8442	1609	88.33	97.81
	Muvau	2	8798	1644	83.57	102.79
	Nziu	1	6538	1358	40.86	160.02
	Wote	Kamunyolo	8246	2506	23.47	351.34
		Wote	4212	218	54.57	193.17

Source: Kenya National Bureau of Statistics (KNBS) (2009). ―2009 Kenya Population and Housing Census Volume 1 A, Population Distribution by Administrative Units, || Nairobi, Kenya National Bureau of Statistics



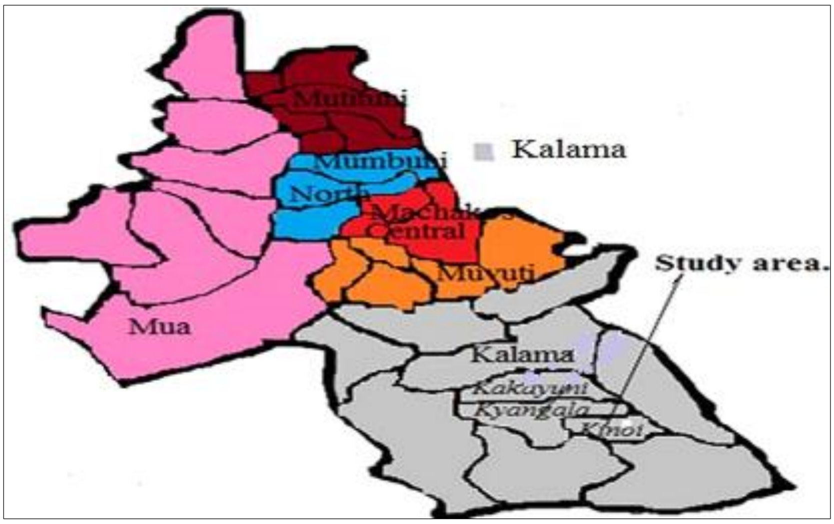
Source: Makueni development plan, 2013

Figure 1 Location of Makueni County in Kenya

2.3. Machakos County study sites

In Machakos County, the study sites included Machakos central Sub-County where a peri-urban site was selected in Mung'ala Sub-location (Ecological Zone 2/3) and Kinoi Sub location in Kalama Sub-County (Ecological zone 4) which is in rural parts of Machakos (MICDP, 2018). In Kalama Sub-County the study was conducted in Kinoi sub-location in

Kyangala location which is in rural areas of Machakos County. The choice of the study site was based on several considerations emanating from the research problem. This area is characterized by deforestation due to forest encroachment by the households for the source of wood fuel. Other areas have been cleared for agricultural activities mostly arable farming; this has led to limited sources of energy fuel hence the need of adopting energy-saving technologies. Bare rocks have been left with little or no soil covering most parts of the study area. The area has steep hills and experiences the highest soil erosion compared to other Sub-locations in the Sub-County (Muloo, *et al.,* 2019).



Source: Machakos development plan, 2013

Figure 2 Location of study area; Kalama Sub-County in Machakos County

2.4. Physical location, population and demography, physiography and hydrological conditions of Kalama Sub-County

The rural site study was undertaken at Kyangala Location, Kinoi Sub-location, and KalamaSub County in Machakos County (Figure 3.2). Kalama Sub-County covers an area of 200 square kilometers, is located between 1º37'S and 1º45'S latitude and 37º15'E and 37º23'E longitude. Kalama Sub-County has four locations and eight sub-locations (Table 3).

Table 3 Population and demographic characteristics of Kalama Sub-County

Sub-County	Location	Sub-location	Total population	Area (Km^2)	Population Density	Households
Kalama	Kola	Iiuni	4,415	26.62	165.87	986
		Katanga	7,695	34.18	225.13	1,643
	Lumbwa	Muumandu	12,475	148.63	83.93	2,820
	Kalama	Nziuni	4,870	17.55	277.44	1,015
		Kiitini	6,285	35.37	177.71	1,419
	Kyangala	Kinoi	2,342	11.89	197.04	543
		Kakayuni	2,454	7.84	312.98	568
		Kyangala	2,298	10.46	219.69	541
Total			7094	30.19	729.71	1652

Source: Kenya National Bureau of Statistics (KNBS) (2009). ―2009 Kenya Population and Housing Census Volume 1 A, Population Distribution by Administrative Units, ‖ Nairobi, Kenya National Bureau of Statistics

The study area, Kalama Sub-County, has metamorphic rocks which form the roots of these mountains (Maree, 2002). The mountains consist of excessively drained, reddish-brown, stony and rocky sandy clay loam soils that vary in depth (Muloo, *et al.,* 2019). The plains and uplands that surround the mountains consist of poorly drained, black cracking and swelling firm clay soils. In the dissected uplands well-drained dark reddish-brown clay and sandy clay soils are formed. The study area is drained by two seasonal rivers: Thwake and Kaiti. According to Muloo, *et al.,* (2019), the mean annual rainfall of the area is 602 mm, distributed over a long (March-May) and a short (October-December) rain season, separated by a distinct dry season. The rains on the southern and eastern slopes of the mountains tend to be prolonged (World Resources Institute (2007).

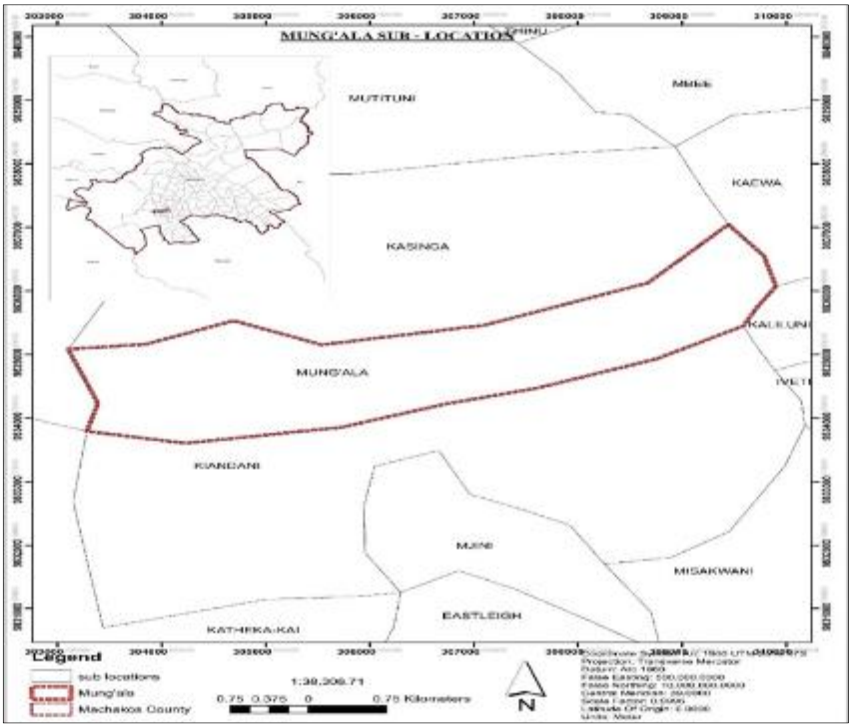
2.5. Population and demographic characteristics of Mumbuni Location Machakos Central Division

Mumbuni location is in Machakos Central Sub-County and the study area is within the Mung'ala Sub-location which boulders Iveti forest on the upper side of the division. Other sub-locations include Kasinga, Upper Kianda, Lower Kianda and Misakwani (Table 3.3). The study area has been deforested for agricultural practices mainly cash crops including coffee, French beans and fruits. Its nearness to the Machakos town has also led to a dense population hence vegetation clearing has been high for settlement. This gives the need for energy-conserving technologies adoption to conserve the available woodfuel and vegetation in general hence limited greenhouse gas emissions table 4.

Table 4 Population and demographic characteristics of Machakos Central Sub-County

Sub-County	Location	Sub-location	Total population	Area (Km^2)	Population Density	Households
Machakos Central	Mumbuni	Mung'ala Kasinga	2,400	8.2	199	550
			8,493	12.6	675	1,934
		Upper Kianda	9,645	7.0	1,380	2,567
		Lower Kianda	11,659	9.7	1,199	3,418
		Misakwani	8,187	10.7	768	1,840
Total			46,151	48.1	5,025	11,652

Source: Kenya National Bureau of Statistics (KNBS) (2009). ―2009 Kenya Population and Housing Census Volume 1 A, Population Distribution by Administrative Units, ‖ Nairobi, Kenya National Bureau of Statistics



Source: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, FAO, NPS, NRCAN, Geo Base, IGN, Kadaster NL, Ordinance Survey, Esri Japan, METI, Esri China (Hong Kong), © Open Street Map contributors, and the GIS User Community

Figure 3 Location of study site; Machakos Central Sub-County in Machakos County

3. Results

3.1. Social- economic factors influencing use of improved energy technology

In the selected Makueni and Machakos areas, significant social-economic effects in the use of these technologies were found to be from; age group of the respondents, gender, education level, Household monthly income and family size,

Family size: More Households having 1 – 3 families were found to be using charcoal energy (80.0%). Similarly, those who had 1 – 3 members in a family used LPG (74.3%), woodfuel (77.2%), Solar energy (83.0%) and electricity (93.1%). Family size had a significant effect on use of LPG (χ^2 = 22.010, P = 0.001) and electric energy technology (χ^2 = 20.482, p = 0.002). (Table 5)

Table 5 Effects of Family size on use of energy technology

Energy device	Category	Respondents using device	%	χ^2 value	P value
Charcoal	1 – 3	144	80		
	4 – 7	34	18.9		
	7 – 10	2	1.2	0.746	0.993
LPG	1 – 3	89	94.7		
	4 – 7	5	5.3		
	7 - 10	0.0	0.0	22.010	0.001
Kerosene	1 – 3	75	74.3		
	4 – 7	26	25.7		
	7 - 10	0.0	0.0	8.592	0.190
Solar energy	1 – 3	93	83.0		
	4 – 7	17	15.2		
	7 - 10	2	1.8	3.614	0.729
Woodfuel energy	1 – 3	132	77.2		
	4 – 7	37	21.6		
	7 - 10	2	1.2	6.863	0.334
Electricity	1 – 3	95	93.1		
	4 – 7	7	6.9		
	7 - 10	0.0	0.0	20.482	0.002
Biogas	1 – 3	3	100		
	4 – 7	0.0	0.0		
	7 - 10	0.0	0.0	0.978	0.986

Age group: A bigger number of those who used charcoal energy (23.9%) were in the age of 21 – 40 years. More of those who used LPG were 21 – 41 years of age (30.9%). Similarly, large number of the respondents using solar (23.2%) were 21 – 30 years of age while those who used kerosene energy (26.7%) were 31 – 41 years. Use of biogas was high among the respondents of 31 - 60 years (33.3%). Respondent ages had significant effects on use of the various energy technologies ($P < 0.05$), table 6.

Table 6a Effects of respondents' Ages on use of Charcoal, LPG, Kerosene and Solar energy technology

Energy device	Category	Respondents using device	%	χ^2 value	P value
Charcoal	20 and below	7	3.9		
	21 – 30	43	23.9		
	31 – 40	43	23.9		
	41 – 50	40	22.2		
	51 – 60	24	13.4		
	Above 60	23	12.8	146.564	0.0001
LPG	20 and below	4	4.3		
	21 – 30	29	30.9		
	31 – 40	22	23.4		
	41 – 50	17	18.1		
	51 – 60	10	10.7		
	Above 60	12	12.8	152.050	0.0001
Kerosene	20 and below	2	2.0		
	21 – 30	21	20.8		
	31 – 40	27	26.7		
	41 – 50	26	25.7		
	51 – 60	12	11.9		
	Above 60	13	12.9	147.784	0.0001
Solar energy	20 and below	5	4.5		
	21 – 30	26	23.2		
	31 – 40	26	23.2		
	41 – 50	22	19.6		
	51 – 60	21	18.8		
	Above 60	12	10.7	152.669	0.0001

Table 6b Effects of respondents' Ages on use of woodfuel, electricity and Biogas energy technology

Energy device	Category	Respondents using device	%	χ^2 value	P value
Woodfuel energy	20 and below	6	3.5		
	21 – 30	36	21.1		
	31 – 40	37	21.1		
	41 – 50	42	21.6		
	51 – 60	26	15.2		
	Above 60	24	14.0	151.439	0.0001
Electricity	20 and below	3	2.9		
	21 – 30	25	24.5		

	31 – 40	29	28.4		
	41 – 50	20	19.6		
	51 – 60	12	11.8		
	Above 60	13	12.7	147.280	0.0001
Biogas	20 and below	0.0	0.0		
	21 – 30	0.0	0.0		
	31 – 40	1	33.3		
	41 – 50	1	33.3		
	51 – 60	1	33.3		
	Above 60	0.0	0.0	145.685	0.0001

Gender of the respondents: Significantly high number of male respondents utilized energy technologies more than female respondents ($P < 0.05$). It was established that significantly ($\chi^2 = 143.091$, $P = 0.0001$) more female respondents (66.6%) were only found in the usage of biogas energy, table 7.

Table 7 Effects of respondents' gender on use of energy technology

Energy device	Category	Respondents using device	%	χ^2 value	P value
Charcoal	Male	106	58.9		
	Female	74	41.1	142.412	0.0001
LPG	Male	52	55.3		
	Female	42	44.7	144.040	0.0001
Kerosene	Male	62	61.4		
	Female	39	38.6	143.612	0.0001
Solar energy	Male	61	54.5		
	Female	51	45.5	144.781	0.0001
Woodfuel energy	Male	105	61.4		
	Female	66	38.6	145.235	0.0001
Electricity	Male	58	56.9		
	Female	44	43.1	143.581	0.0001
Biogas	Male	1	33.3		
	Female	2	66.6	143.091	0.0001

Education level of the respondents: Respondents' level of education had a significant effect on the use of the energy ($P < 0.05$). Use of charcoal and LPG were high among those having secondary education (42.2% and 50.0% respectively). Similarly, use of solar (42.9%), woodfuel (38.0%) and electricity (41.2%) were higher among those who had secondary education. Biogas energy was mainly associated with those who had university education (66.6%).

Table 8a Effects of respondents' education level on use of charcoal, LPG, Kerosene and Solar energy technology

Energy device	Category	Respondents using device	%	χ^2 value	P value
Charcoal	Uneducated	9	5.0		
	Primary	46	25.6		
	Secondary	76	42.2		
	University	42	23.3		
	College	7	3.9	154.101	0.0001
LPG	Uneducated	0.0	0.0		
	Primary	7	7.4		
	Secondary	47	50.0		
	University	32	34.0		
	College	8	8.5	195.023	0.0001
Kerosene	Uneducated	10	9.9		
	Primary	39	38.6		
	Secondary	33	32.7		
	University	17	16.8		
	College	2	2.0	168.138	0.0001
Solar energy	Uneducated	9	8.0		
	Primary	25	22.3		
	Secondary	48	42.9		
	University	27	24.1		
	College	3	2.7	148.788	0.0001

Table 8b Effects of respondents' education level on use of woodfuel, electricity and biogas technology

Energy device	Category	Respondents using device	%	χ^2 value	P value
Woodfuel energy	Uneducated	15	8.8		
	Primary	51	29.8		
	Secondary	65	38.0		
	University	34	19.9		
	College	6	3.5	161.867	0.0001
Electricity	Uneducated	6	5.9		
	Primary	23	22.5		
	Secondary	42	41.2		
	University	24	23.5		
	College	7	6.9	145.931	0.0001
Biogas	Uneducated	0.0	0.0		
	Primary	0.0	0.0		
	Secondary	0.0	0.0		
	University	2	66.6		
	College	1	33.3	153.158	0.0001

Household Monthly income: Considering monthly income in a household, the study found out that; there was a significant effect of the monthly income on the use of current energy technology. Use of Biogas and wind mill energy were not significantly affected by the house head monthly income ($\chi^2 = 12.331$, p = 0.137, and $\chi^2 = 3.949$, p = 0.413, and respectively). However, HH monthly income significantly influenced usage of charcoal, LPG, Kerosene, Solar energy, woodfuel and electricity ($P < 0.05$).

Table 9a Effects of Household monthly income level on use of charcoal, LPG, Kerosene and Solar energy technology

Energy device	Category	Respondents using device	%	χ^2 value	P value
Charcoal	Less than Ksh. 5000	38	21.1		
	5000 – 10000 ksh.	99	55.0		
	10000-20000	36	20.0		
	20000 – 30000	3	1.7		
	Above 30000	4	2.2	16.360	0.038
LPG	Less than Ksh. 5000	21	22.3		
	5000 – 10000 ksh.	47	50.0		
	10000-20000	15	16.0		
	20000 – 30000	3	3.2		
	Above 30000	8	8.5	17.117	0.009
Kerosene	Less than Ksh. 5000	26	25.7		
	5000 – 10000 ksh.	54	53.5		
	10000-20000	21	20.8		
	20000 – 30000	0.0	0.0		
	Above 30000	0.0	0.0	20.046	0.010
Solar energy	Less than Ksh. 5000	15	13.4		
	5000 – 10000 ksh.	69	61.6		
	10000-20000	24	21.4		
	20000 – 30000	3	2.7		
	Above 30000	1	0.9	16.355	0.038

Table 9b Effects of Household monthly income level on use of woodfuel, LPG, and Biogas energy

Energy device	Category	Respondents using device	%	χ^2 value	P value
Woodfuel energy	Less than Ksh. 5000	36	21.1		
	5000 – 10000 ksh.	96	55.6		
	10000-20000	34	19.9		
	20000 – 30000	4	2.3		
	Above 30000	2	1.2	21.796	0.005
Electricity	Less than Ksh. 5000	29	28.4		
	5000 – 10000 ksh.	42	41.2		
	10000-20000	22	21.6		

	20000 – 30000	1	1.0		
	Above 30000	8	7.8	29.157	0.0001
Biogas	Less than Ksh. 5000	0.0	0.0		
	5000 – 10000 ksh.	2	66.7		
	10000-20000	0.0	0.0		
	20000 – 30000	0.0	0.0		
	Above 30000	1	33.3	12.331	0.137

Size of the land: Significant effect of the size of the land was noted on use of kerosene, woodfuel and electricity ($P < 0.05$). More of the respondents who used kerosene (65.3%), electricity (79.4%), solar energy (39.3%) and woodfuel energy (46.2%), had smaller sizes of land below 2 acres. However, Land size owned had no significant effects on the use of charcoal, LPG and biogas energy ($P > 0.05$).

Table 10a Effects of land size on use of charcoal, LPG, Kerosene and solar energy technology

Energy device	Category	Respondents using device	%	χ^2 value	P value
Charcoal	Below 2 acres	91	50.6		
	3 – 6	56	31.1		
	6 – 8	26	14.4		
	9 – 11	7	3.9	5.204	0.518
LPG	Below 2 acres	50	53.2		
	3 – 6	32	34.0		
	6 – 8	9	9.6		
	9 – 11	3	3.2	5.909	0.433
Kerosene	Below 2 acres	66	65.3		
	3 – 6	22	21.8		
	6 – 8	12	11.9		
	9 – 11	1	1.0	16.440	0.012

Table 10b Effects of land size on use of woodfuel, electricity and biogas technology

Energy device	Category	Respondents using device	%	χ^2 value	P value
Woodfuel energy	Below 2 acres	79	46.2		
	3 – 6	56	32.2		
	6 – 8	30	17.5		
	9 – 11	7	4.1	19.682	0.003
Electricity	Below 2 acres	81	79.4		
	3 – 6	14	13.7		
	6 – 8	6	5.9		
	9 – 11	1	1.0	59.403	0.0001
Biogas	Below 2 acres	3	100		
	3 – 6	0.0	0.0		
	6 – 8	0.0	0.0		
	9 – 11	0.0	0.0	5.064	0.536

3.2. Logistic Regression analysis of influence of socioeconomic factors on use of technology devices

Using linear regression analysis on factors affecting use of charcoal energy devices, the result showed that, usage of charcoal was positively affected by age (t-value=0.043), family size (t-value=-1.002) and education levels (t-value=-1.226).

Table 11 Regression table showing effect of socioeconomic factors on charcoal energy

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.325	0.136		9.776	0.000
	Gender	-0.013	0.030	-0.029	-0.422	0.673
	Age group	0.000	0.006	0.003	0.043	0.966
	Family size	-0.053	0.053	-0.073	-1.002	0.318
	Education level	-0.033	0.027	-0.090	-1.226	0.222
a. Dependent Variable: do you usually use charcoal energy devices						

Social-economic factors affecting use of LPG energy devices, showed a positive effect of by family size (t-value=2.641), age (t-value=-0.854), gender (t-value=-0.292) and education (t-value=-6.608).

Table 12 Regression table showing effect of socioeconomic factors on LPG energy

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.020	0.166		12.178	0.000
	Gender	-0.011	0.037	-0.018	-0.292	0.771
	Age group	-0.007	0.008	-0.052	-0.854	0.394
	Family size	0.173	0.065	0.168	2.641	0.009
	Education level	-0.216	0.033	-0.423	-6.608	0.000
a. Dependent Variable: do you LPG energy devices						

Use of kerosene energy was positively affected by gender (t-value=1.636), age (t-value=1.298), family size (t-value=0.234) and education level (t-value=4.626).

Table 13 Regression table showing effect of socioeconomic factors on kerosene energy

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.877	0.181		4.834	0.000
	Gender	0.066	0.040	0.108	1.636	0.103
	Age group	0.011	0.009	0.086	1.298	0.196
	Family size	0.017	0.071	0.016	0.234	0.815
	Education level	0.165	0.036	0.322	4.625	0.000
a. Dependent Variable: do you use kerosene energy devices						

Socio economic factors of family size (t-value=0.202) and education (t-value=0.156) positively affected use of solar energy. However, gender (t-value=-1.476) and age group (t-value=-0.646) had negative effects on Solar energy usage.

Table 14 Regression table showing effect of socio-economic factors on solar energy

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.547	0.191		8.112	0.000
	Gender	-0.063	0.042	-0.103	-1.476	0.141
	Age group	-0.006	0.009	-0.045	-.646	0.519
	Family size	0.015	0.075	0.015	0.202	0.840
	Education level	0.006	0.038	0.011	0.156	0.876
a. Dependent Variable: do you use solar energy devices						

Education levels of the respondents were found to significantly affect use of woodfuel ($P < 0.05$). Age and family size negatively affected use of woodfuel energy. However, the effects were not statistically significant ($P > 0.05$).

Table 15 Regression table showing effect of socio-economic factors on solar energy

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.943	0.144		6.566	0.000
	Gender	0.028	0.032	0.059	0.876	0.382
	Age group	-0.005	0.007	-0.047	-0.706	0.481
	Family size	-0.067	0.057	-0.083	-1.187	0.237
	Education level	0.104	0.028	0.259	3.688	0.000
a. Dependent Variable: do you use woodfuel energy devices						

Use of electricity was significantly affected positively by the family size of a household ($P < 0.05$). Age, gender and education level positively affected use of electricity although the effects were not significant ($P > 0.05$).

Table 16 Regression table showing effect of socio-economic factors on electricity energy

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.065	0.183		5.816	0.000
	Gender	0.027	0.041	0.044	0.652	0.515
	Age group	0.012	0.009	0.091	1.371	0.172
	Family size	0.302	0.072	0.293	4.193	0.000
	Education level	7.868E-5	0.036	0.000	0.002	0.998
a. Dependent Variable: do you electricity energy devices						

Education level of the respondents significantly affected use of biogas energy ($P < 0.05$). Other factors, gender, age and family size negatively affected use of biogas energy although not to a significant level ($P > 0.05$).

Table 17 Regression table showing effect of socio-economic factors on use of biogas energy

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.064	0.045		46.054	0.000
	Gender	-0.007	0.010	-0.046	-0.672	0.503
	Age group	-0.001	0.002	-0.022	-0.314	0.754
	Family size	-0.001	0.018	-0.004	-0.054	0.957
	Education level	-0.022	0.009	-0.180	-2.484	0.014
a. Dependent Variable: do you use biogas energy devices						

4. Discussion

The social status of the respondent interrogated in this study include; type of housing, family size, age group of the respondents, marital status, gender, relationship of the respondents to household head, occupation and education level, majority of the respondents were males. Most of the respondents were married and were aged between 21 – 40 years. Types of housing the respondents lived mainly in brick walled houses and iron sheet roofed. In this community, the two major occupations were farming and business. This gave the residents an average monthly income which could have attributed to high ability in adopting most energy devices. However, it was noted that the farm sizes were merely below 2 acres. In the selected Makueni and Machakos areas, significant social-economic factors affect the use of energy technologies. Families with 1 – 3 members highly used LPG; indicating that households with more members were less likely to use these improved energy technologies. Households with more members are more likely to have less savings (due to high total expenditures) and hence the reason why technologies with huge initial cost such as LPG, solar and electricity energy devices could be out of reach by such households.

According to Papada & Kaliampakos, (2020) the failure to adopt better charcoal stoves in urban and rural was mostly attributed to poor quality of the improved stoves, pricing, information, and education on the stoves. Use of charcoal and LPG were high among those having secondary education. Similarly, use of solar, woodfuel and electricity were higher among those who had secondary education. Biogas energy was mainly associated with those who had university education. Education level can significantly influence energy device adoption in the study areas. This could most likely be attributed to knowledge of the advantages and disadvantages of the energy technologies; this is supported by IRENA (2018), which noted that technology diffusion is restricted by the lack of data. Household head monthly income significantly influenced usage of charcoal, LPG, Kerosene, Solar energy, woodfuel and electricity. indicating that households with more monthly incomes were more likely to use charcoal, kerosene and wood fuel improved energy technologie**s.** More of the respondents who used kerosene, electricity, solar energy and woodfuel energy had smaller sizes of land below 2 acres. However, Land size owned had no significant effects on the use of charcoal, LPG and biogas energy. Respondents with more land were more likely to use wood fuel as improved energy technologies. Wood fuel is a byproduct of land utilization through tree farming and hence a cheaper option for farmers with more land as compared to those with less land.

Using linear regression analysis on factors affecting use of charcoal energy devices, the result showed that, usage of charcoal was positively affected by age, but negatively affected by family size and education levels. Social-economic factors affecting use of LPG energy devices, showed a positive effect of by family size. Age, gender and education level negatively affected use of LPG energy. Use of kerosene energy was positively affected by gender, age, family size and education level of the respondents; this is supported by Papada & Kaliampakos, (2020) who noted that the adoption of given energy device is affected by pricing, information, and education on the energy device. Socio economic factors of family size and education positively affected use of solar energy devices. However, gender and age group had negative effects on Solar energy usage. Education levels of the respondents was found to significantly affect use of woodfuel energy devices. Age and family size negatively affected use of woodfuel energy devices. However, the effects were not statistically significant. Use of electricity was significantly affected positively by the family size of a household. Age, gender and education level positively affected use of electricity although the effects were not significant. Education level of the respondents significantly affected use of biogas energy. Other factors, gender, age and family size negatively affected use of biogas energy although not to a significant level.

5. Conclusion

From the results obtained in this study, it is be concluded that: Social-economic factors such as income, education level and household size highly influenced adoption of improved energy technologies in the study areas.

Recommendations

Based on the results obtained in this study, it is recommended that; there is need for more research on Impacts of education level on adoption of various improved energy devices.

Compliance with ethical standards

Acknowledgments

First and foremost, I am extremely grateful to; Prof. Jacinta M. Kimiti, Dr. Muusya Mwinzi and Dr. George M. Muthike for their invaluable advice, continuous support, and patience. Their immense knowledge and plentiful experience have encouraged in all the time of my research and daily life. Finally, I would like to express my gratitude to farmers where I collected data, my parents, wife and children. Without their tremendous understanding and encouragement over the past few years, it would have been impossible to complete this research. God bless you all.

Disclosure of conflict of interest

There was no conflict of interest in publication of this paper. All the authors were consulted and they agreed to have the paper published. No funding body was involved in the research.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

[1] African Development Bank (AfDB). (2017). The New Deal on Energy for Africa: a Transformative Partnership to Light Up and Power Africa by 2015, AfDB, Abidjan, Côte d'Ivoire.

[2] Bergmann C, Roden P, Nüsser M. Contested fuelscapes: Producing charcoal in sub-Saharan drylands. Area. 2019 Mar, 51(1):55-63.

[3] Bhagavan MR. Energy utilities and institutions in Africa.

[4] Bhatta B. Analysis of urban growth and sprawl from remote sensing data. Springer Science & Business Media, 2010 Mar 3.

[5] Broesamle H, Mannstein H, Schillings C, Trieb F. Assessment of solar electricity potentials in North Africa based on satellite data and a geographic information system. Solar Energy. 2001 Jan 1, 70(1):1-2.

[6] Doggart N, Meshack C. The marginalization of sustainable charcoal production in the policies of a modernizing African nation. Frontiers in Environmental Science. 2017 Jun 8, 5:27.

[7] Duffie JA, Beckman WA. Solar engineering of thermal processes. John Wiley & Sons, 2013 Apr 15. Duffie, A. J., & Beckman, A. W. (2013). Solar Engineering of Thermal Processes, (4th Edition.), John Wiley and Sons 910: 373-375.

[8] Elvira M. Choice determinants for (non)-adoption of energy efficient technologies in households. IIIEE Reports. 2008.

[9] Food and Agriculture Organization (FAO). (2017). Incentivizing sustainable wood energy in sub-Saharan Africa: a way forward for policy-makers. Rome.

[10] Food and Agriculture Organization (FAO). (2018). The State of the World's Forests 2018 - Forest pathways to sustainable development. Rome, FAO. (Also available at http://www.fao.org/3/I9535EN/i9535en.pdf) (Accessed, 6/1/2021)

[11] Federal Emergency Management Agency (FEMA). (2007). Energy security and sustainability in Africa, Trade Autoprint, Nairobi. 41, 18-21

[12] Food and Agriculture Organization of the United Nations (FAO). (2019). Biodiversity for food and agriculture and ecosystem services. Thematic study prepared for the SoW-BFA. Rome.

[13] Food and Agriculture Organization of the United Nations (FAO). (2022). The state of the World's Forests. Forest pathways for green recovery and building inclusive, resilience and sustainable economies. Rome, FAO. https://doi.org/10.4060/cb9360en (Accessed, 4/6/2022)

[14] Foster, R., Ghassemi, M., & Cota, A. (2009). "Section 5.16.3 Solar-powered products". Solar Energy: Renewable Energy and the Environment. Boca Raton, Florida: CRC Press 337: 265-295.

[15] Githiomi JK, Mugendi DN. Household tree planting and its related constraints in meeting woodfuel production in Kiambu, Thika and Maragwa Districts of Central Kenya. Journal of Horticulture and Forestry. 2012 Apr 22, 4(7):120-5.

[16] Panepinto D, Riggio VA, Zanetti M. Analysis of the emergent climate change mitigation technologies. International Journal of Environmental Research and Public Health. 2021 Jun 24, 18(13):6767.

[17] Intergovernmental Panel on Climate Change (IPCC). (2019). Renewable energy and Climate Change mitigation. Contribution of Working Group II to the Fourth Assessment Report of the IPPC. Cambridge: Cambridge University Press.

[18] International Energy Agency (IEA). (2002). World Energy Outlook. OECD/IEA, Paris.

[19] International Energy Agency (IEA). (2017). World Energy Outlook. OECD/IEA, Paris.

[20] International Renewable Energy Agency (IRENA). (2018). Project Navigator (online platform), International Renewable Energy Agency, AbuDhabi, https://navigator.irena.org/index.html (accessed 3/9/2020).

[21] Jeffery, S., Bezemer, T. M., Cornelissen, G., Kuyper, T. W., Lehmann, J., & Mommer, L. (2015). The way forward in biochar research: targeting trade-offs between the potential wins. GCB Bioenergy, 7:1–13. https://doi.org/10.1111/gcbb.12132.) (Accessed, 3/5/2022)

[22] Johnson, M., & Chiang, R. (2015). Quantitative guidance for stove usage and performance to achieve health and environmental targets. Environmental Health Perspectives 123, 820–826.

[23] Karekezi, S., & Kithyoma, W. (2002). 'Renewable Energy Strategies for Rural Africa: is a PV-led renewable energy strategy the right approach for providing modern energy to the rural poor of sub-Saharan Africa?' Energy Policy, Vol. 30 Nos. 11-12, Special Issue – Africa: Improving Modern Energy Services for the Poor. Oxford: Elsevier Science Limited.

[24] Kenya National Bureau of Statistics (KNBS). (2009). Kenya Population and Housing Census, 2009 Kenya National Bureau of Statistics, Nairobi. 23, 1-23.

[25] Kieti, R. N, Kauti, M. K, Kisangau, D. P. (2016). Biophysical Conditions and Land Use Methods Contributing to Watershed Degradation in Makueni County, Kenya. J Ecosys Ecograph 6: 216. doi: 10.4172/2157-7625.1000216

[26] Kiruki, H. M., Van der Zanden, E. H., Malek, Z., & Verburg, P. H. (2017). Land cover change and woodland degradation in a charcoal producing semi-arid area in Kenya. Land Degradation and Development, 28, 472–481.

[27] Lambe F, Jürisoo M, Wanjiru H, Senyagwa J. Bringing clean, safe, affordable cooking energy to households across Africa: an agenda for action. Prepared by the Stockholm Environment Institute, Stockholm and Nairobi, for the new climate economy. 2015 Oct 24.

[28] Lotter D, Hunter N, Straub M, Msola D. Microgasification cookstoves and pellet fuels from waste biomass: A cost and performance comparison with charcoal and natural gas in Tanzania. African Journal of Environmental Science and Technology. 2015 Sep 4, 9(6):573-83.

[29] Machakos Integrated County Development plan (MICDP). (2018). Government of Machakos. 1, 8, 18 and 32.

[30] Majid, E. (2006). www.bioenergy list.org (Accessed, 1/3/2022).

[31] Makueni Integrated County Development Plan (MICDP), (2018). Government of Makueni. 2, 18 and 22.

[32] Makueni County Spatial Plan (2019). Government of Makueni County. 3, 93 and 94.

[33] Maree, M. (2002). The formation of the escarpment in the Chuka-South Area, Kenya. M.Sc. report, Laboratory of Soil Science and Geology, Wageningen University. The Netherlands.

[34] Mills E. Identifying and reducing the health and safety impacts of fuel-based lighting. Energy for Sustainable Development. 2016 Feb 1, 30:39-50.

[35] Ministry of Energy. (2004). The Energy Bill, 2004. Nairobi: Ministry of Energy. 141, 119-141.

[36] Muchiri, L. (2008). Gender and Equity in Bio-energy access and Delivery in Kenya. PISCES 24:15-16.

[37] Mungenda, A., & Mungenda, O. (2013). Research methods: Quantitative and qualitative approaches. Nairobi: ACTS Press. National Center for Education Statistics, 2005. State non-fiscal public elementary/ secondary education survey. American Counseling Association.

[38] Mugo, F., & Gathui, T. (2010). Biomass energy use in Kenya. A background paper prepared for the International Institute for Environment and Development (IIED) for an international ESPA workshop on biomass energy, 19–21 October 2010, Parliament House Hotel, Edinburgh. Practical Action, Nairobi, Kenya. 31, 7-10 and 16.

[39] Masila SM. Effects of land degradation on agricultural land use: a case study of smallholder farmers indigenous knowledge on land use planning and management in Kalama division, Machakos county (Doctoral dissertation).

[40] Nahar M, Khan MH, Ahmad SA. Indoor Air Pollutants and Respiratory Problems among Dhaka City Dwellers. Arch Community Med Public Health 2 (1): 032-036. DOI: 10.17352/2455-5479.000014. Archives of Community Medicine and Public Health. 2016, 32.

[41] Njenga M, Mahmoud Y, Mendum R, Iiyama M, Jamnadass R, De Nowina KR, Sundberg C. Quality of charcoal produced using micro gasification and how the new cook stove works in rural Kenya. Environmental Research Letters. 2017 Aug 22, 12(9):095001.

[42] Githiomi JK, Oduor N. Strategies for sustainable wood fuel production in Kenya. Oduor, N., & Githiomi, J. K. (2012). Strategies for sustainable wood fuel production in Kenya Int. J. Appl. Sci. Technol. 2 21–5.

[43] Papada L, Kaliampakos D. Being forced to skimp on energy needs: A new look at energy poverty in Greece. Energy Research & Social Science. 2020 Jun 1, 64: 101450.

[44] Pilishvili T, Loo JD, Schrag S, Stanistreet D, Christensen B, Yip F, Nyagol R, Quick R, Sage M, Bruce N. Effectiveness of six improved cookstoves in reducing household air pollution and their acceptability in rural Western Kenya. PLoS One. 2016 Nov 15, 11(11):e0165529.

[45] Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI). (2016). Employment and Income Effects of Improved Cook Stove and Pico-Solar Interventions. An Impact Evaluation of the EnDev Kenya Programme.

[46] Sawin, J. S. (2017). Renewables Global Status Report, || 2013, http://www.ren21.net/wpcontent/uploads/2017/06/GSR2017 (Accessed 10/9/2021).

[47] Sikei G, Mburu J, Lagat J. Rural households’ response to fuelwood scarcity around Kakamega forest, Western Kenya. 2009.

[48] Smith E. DIY solar projects: How to put the sun to work in your home. Creative Publishing International, 2011 Oct 1.

[49] Tun MM. An overview of renewable energy sources and their energy potential for sustainable development in Myanmar. European Journal of Sustainable Development Research. 2019 Feb 6, 3(1):em0071.

[50] United Nation Environment Programme (UNEP). (2017). Atlas of Africa Energy Resources. UNEP, Nairobi.

[51] Wafula EM, Kinyanjui MM, Nyabole I, Tenambergen ED. Effect of improved stoves on prevalence of acute respiration infection and conjuctivitis among children and women in a rral community in Kenya. East African Medical Journal. 2000, 77(1).

[52] World Bank. (2017). Progress toward Sustainable Energy. Global Tracking Framework 2017, Summary Report. Washington, DC: World Bank.

[53] World Bank. (2019). Kenya Economic Update, April 2019/Edition No. 19. Nairobi Kenya.

[54] World Health Organization (WHO). (2016). Burning opportunity: clean household energy for health, sustainable development and wellbeing of women and children. Geneva, Switzerland.

[55] World Resources Institute. (2007). Nature’s Benefits in Kenya, An Atlas of Ecosystems and Human Well-Being. Washington, DC and Nairobi: World Resources Institute.

[56] Yang B, Li C, Li M, Pan K, Wang D. Application of ARIMA model in the prediction of the gross domestic product. In2016 6th International Conference on Mechatronics, Computer and Education Informationization (MCEI 2016) 2016 Dec (pp. 1258-1262). Atlantis Press.

[57] Yang CJ, Zhou Y, Jackson RB. China's fuel gas sector: History, current status, and future prospects. Utilities Policy. 2014 Mar 1, 28: 12-21.